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(54) **SATCOM GSM SOLUTION DIRECTLY COMMUNICATE WITH GSM PHONES**

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(52) **U.S. Cl.**
CPC **H04B 7/18513** (2013.01); **H04B 7/01** (2013.01); **H04B 7/1853** (2013.01)

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CPC H04B 7/18513; H04B 7/01; H04B 7/1853; H04B 7/18504; H04B 7/18506; H04B 7/18508; H04W 84/005; H04W 84/06
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,552,798 A 9/1996 Dietrich et al.
5,918,157 A 6/1999 Wiedeman et al.
(Continued)

FOREIGN PATENT DOCUMENTS

EP 1091506 A2 4/2001
WO WO-2020/074747 A1 4/2020

OTHER PUBLICATIONS

Caini, Carlo, et al. "A spectrum-and power-efficient EHF mobile satellite system to be integrated with terrestrial cellular systems." IEEE Journal on selected areas in communications 10.8 (1992): 1315-1325. (Year: 1992).*

(Continued)

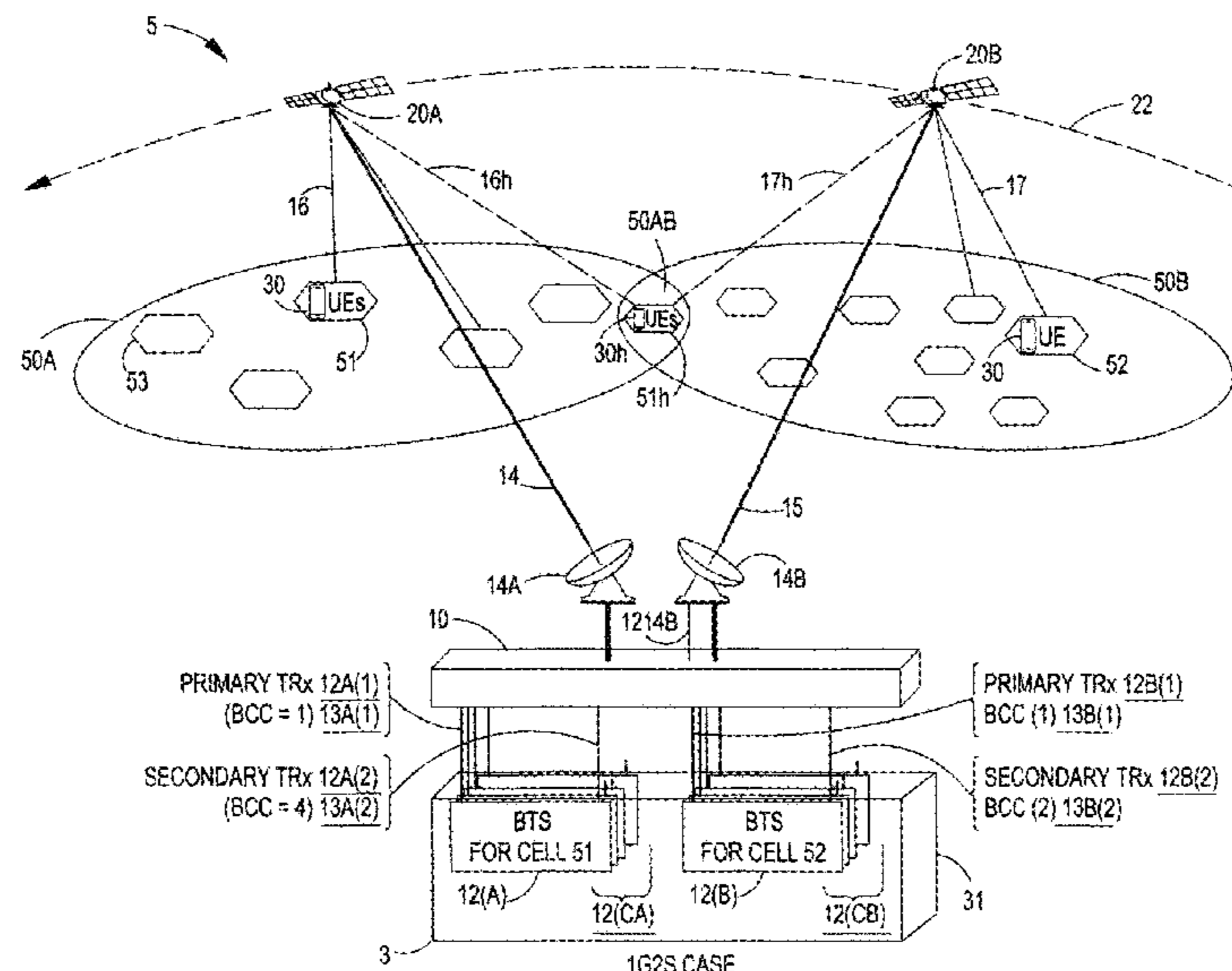
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(57) **ABSTRACT**

A GSM satellite communication system is in communication with a first satellite having a first field of view including a first plurality of cells in which a plurality of active User Equipment (UEs) are located. The plurality of active UEs are in direct communication with the first satellite. The satellite communication system includes a first feeder link and a first tracking antenna configured to communicate with the plurality of active UEs via the first satellite directly serving the first plurality of cells; a first processing device configured to communicate with the plurality of active UEs; and a second processing device configured to normalize

(Continued)



delay for a plurality of beam centers of the first plurality of cells, and provide the normalized delay to the first processing device.

19 Claims, 6 Drawing Sheets

Related U.S. Application Data

- (60) Provisional application No. 63/165,404, filed on Mar. 24, 2021, provisional application No. 63/146,322, filed on Feb. 5, 2021.

(56) References Cited

U.S. PATENT DOCUMENTS

8,914,022 B2 * 12/2014 Kostanic H04B 7/18508
 455/431
 11,031,999 B1 * 6/2021 Liu H04W 74/006
 11,159,228 B2 10/2021 Avellan
 11,463,159 B2 * 10/2022 Yu H04B 7/18513
 2004/0207556 A1 10/2004 Spilker, Jr. et al.

2006/0154660 A1 7/2006 Waugh et al.
 2017/0289939 A1 * 10/2017 Hreha H04W 72/0453
 2017/0290012 A1 * 10/2017 Hreha H01Q 21/24
 2019/0053234 A1 * 2/2019 Cui H04W 72/0446
 2019/0238216 A1 8/2019 Avellan et al.
 2021/0029658 A1 1/2021 Mahalingam et al.

OTHER PUBLICATIONS

Kræmer, Thomas, et al. "Comparing SAR-based short time-lag cross correlation and Doppler-derived sea ice drift velocities." IEEE Transactions on Geoscience and Remote Sensing 56.4 (2017): 1898-1908 (Year: 2017).*

"Digital Cellular Telecommunications System (Phase 2+); Physical Layer on the Radio Path; General Description (GSM 05.01)", GSM—Global System for Mobile Communications, European Telecommunications Standards Institute, May 1996, 20 Pages.

International Search Report & Written Opinion for PCT/US2022/015502, dated May 2, 2022, 19 pgs.

M. Morant, et al., "Experimental Demonstration of MM-Wave 5G NR Photonic Beamforming Based on ORRs and Multicore Fiber", IEEE Transactions on Microwave Theory and Techniques, 67.7, 2019; pp. 2928-2935.

* cited by examiner

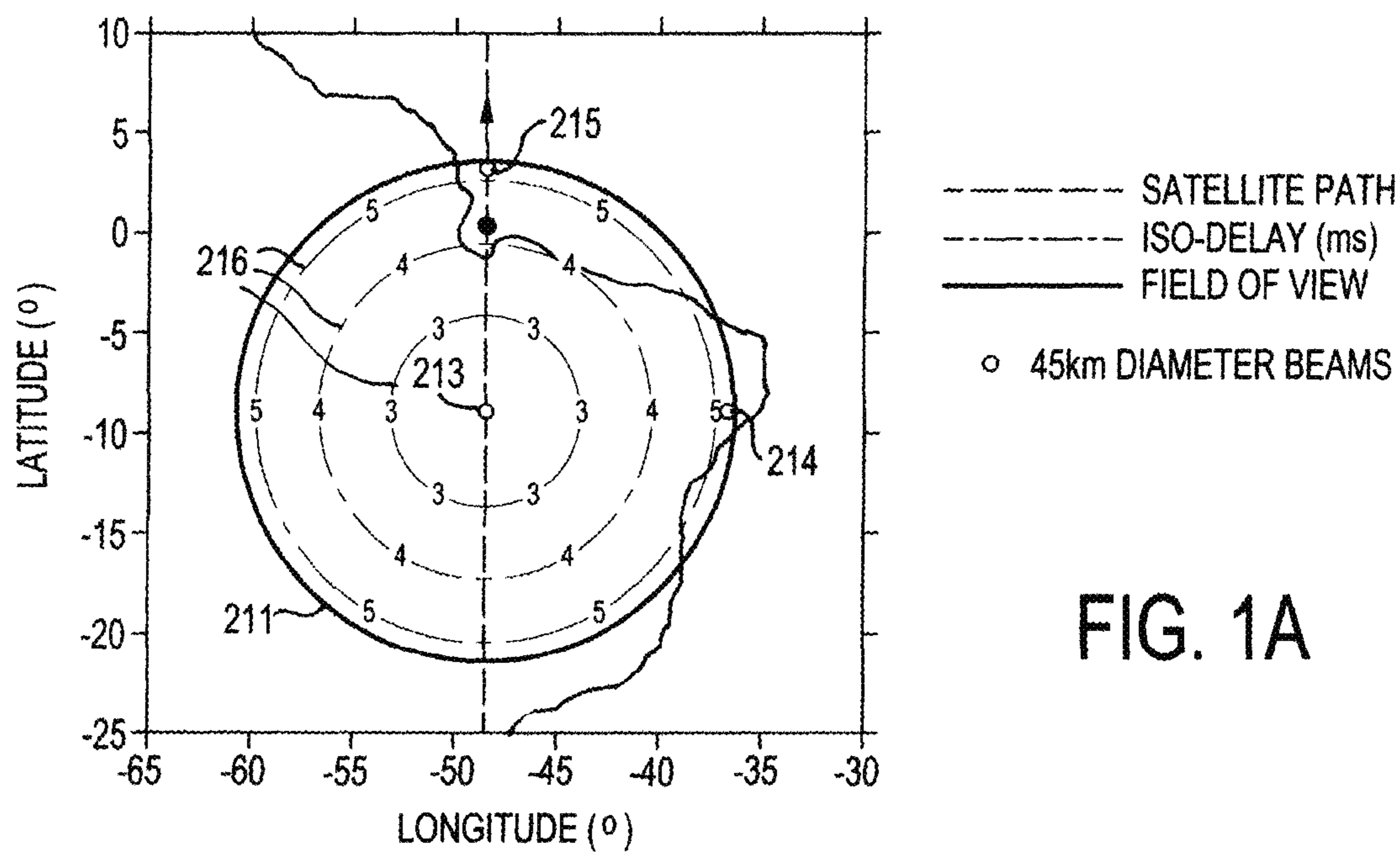


FIG. 1A

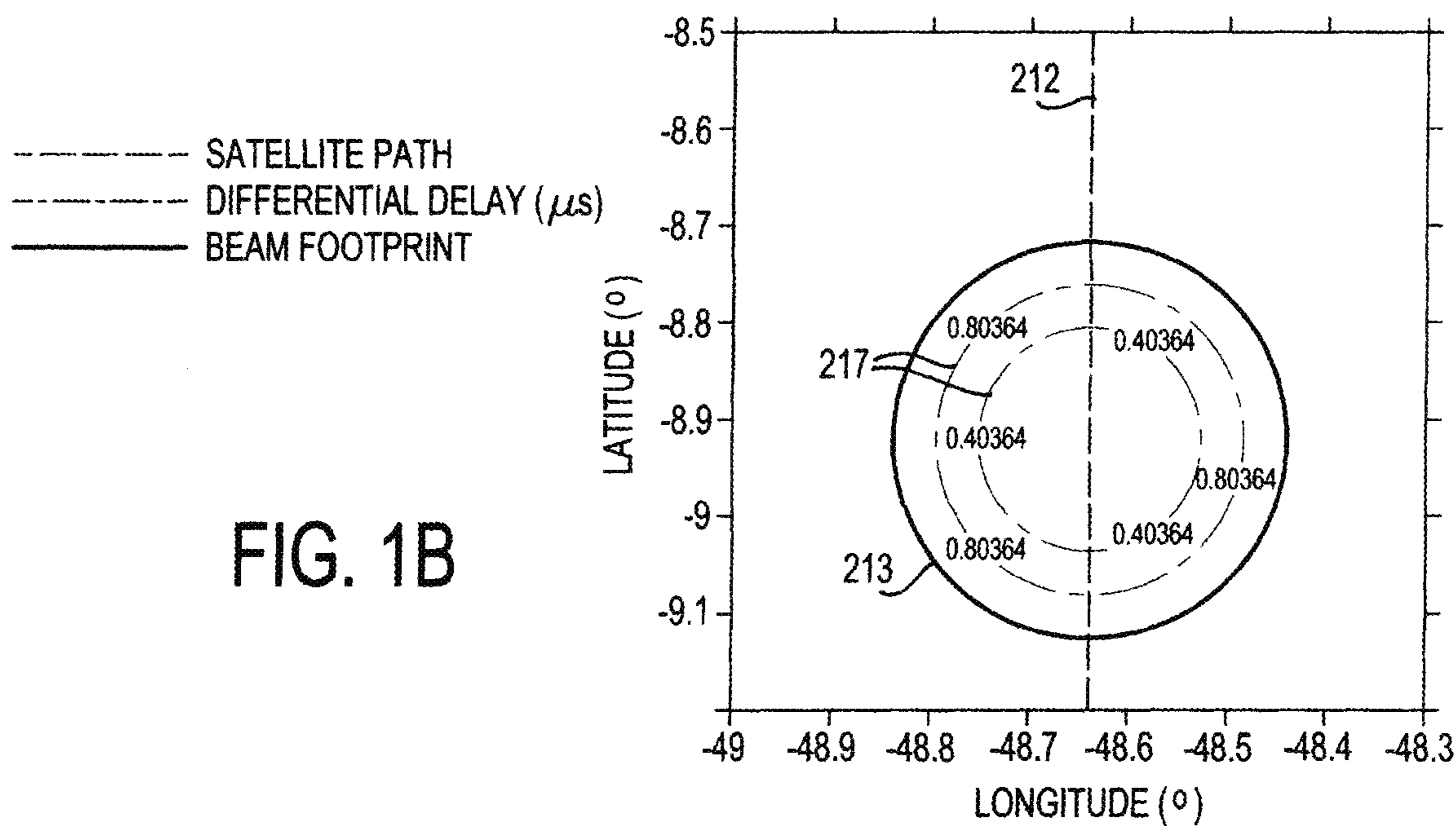
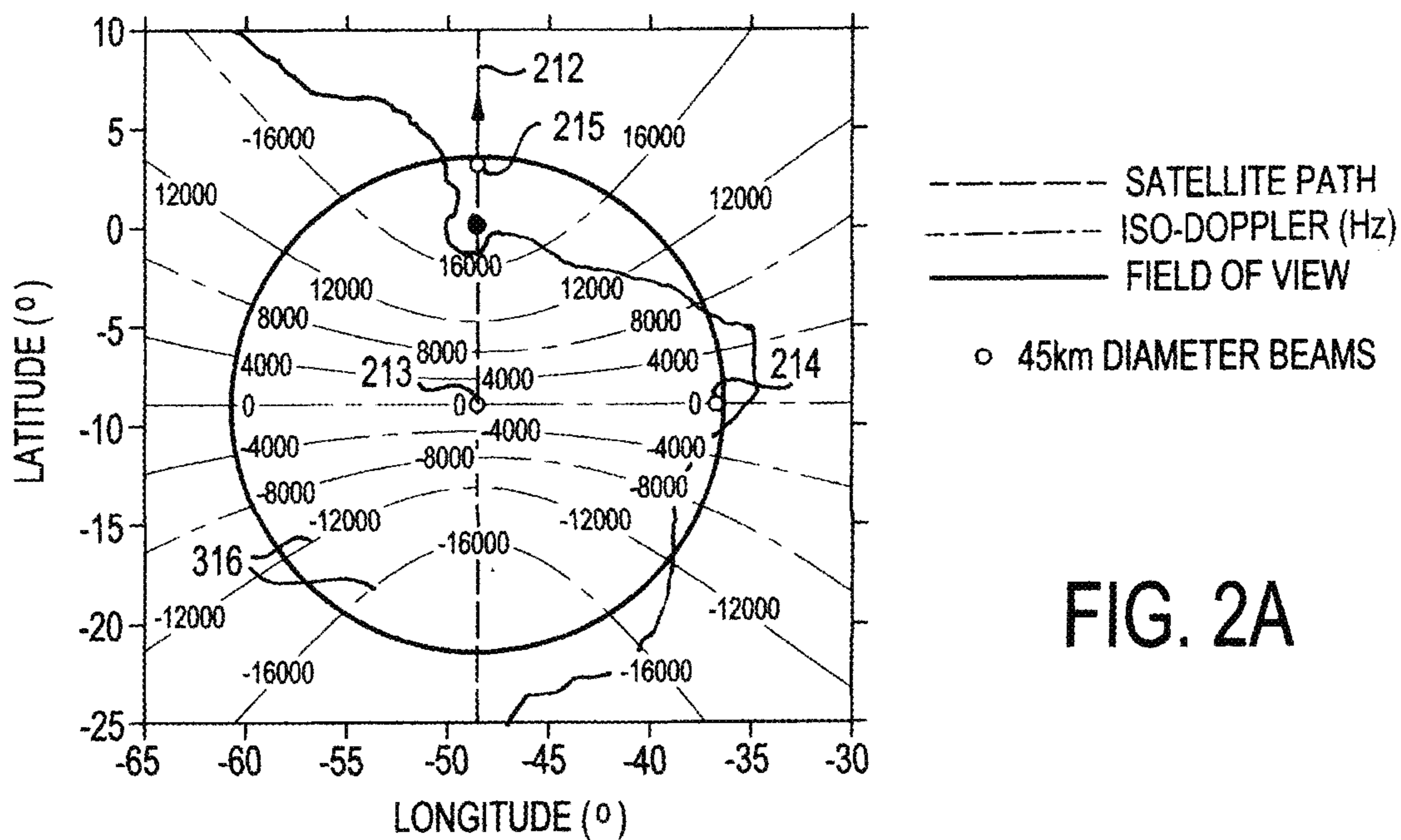
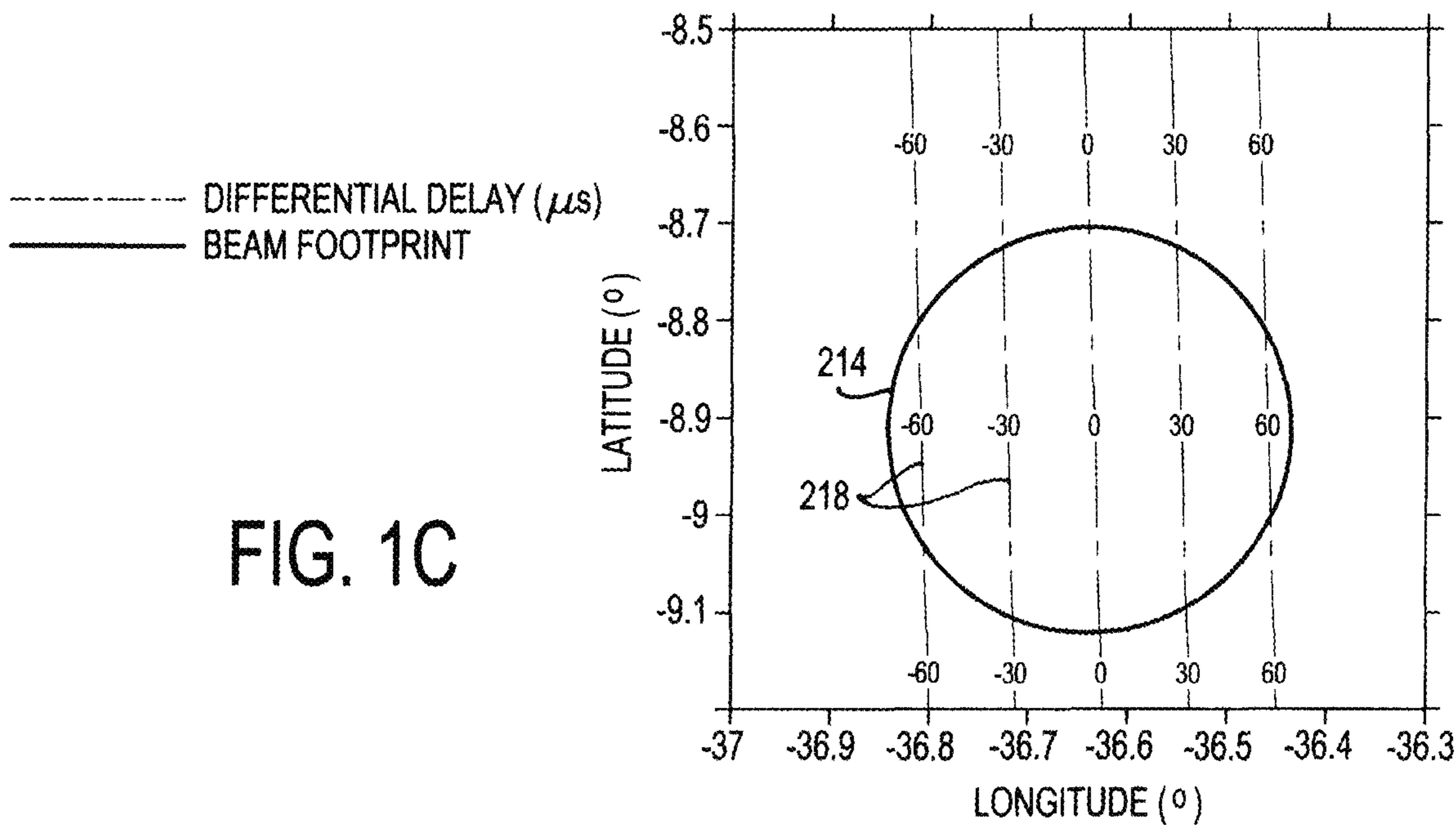
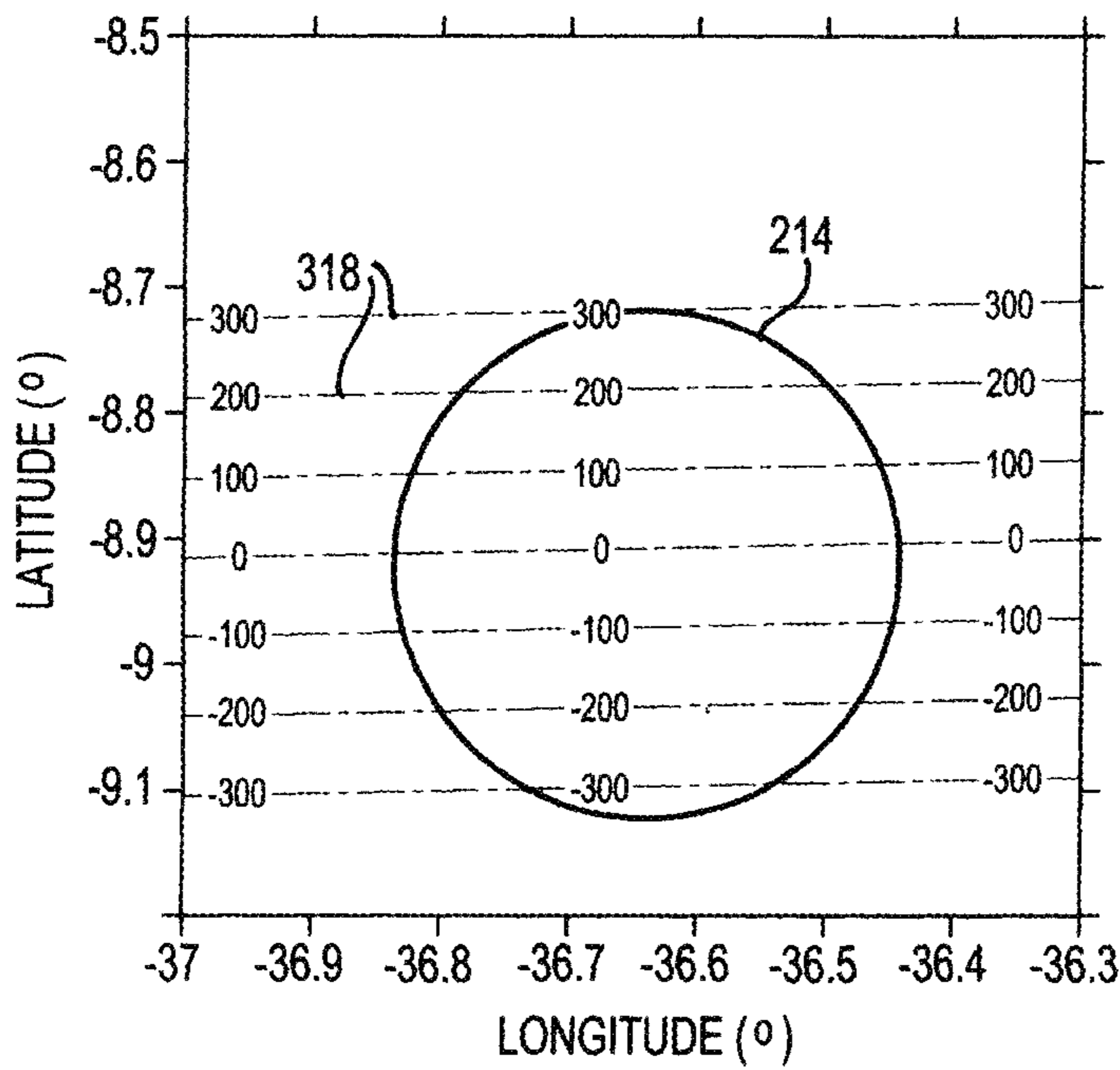
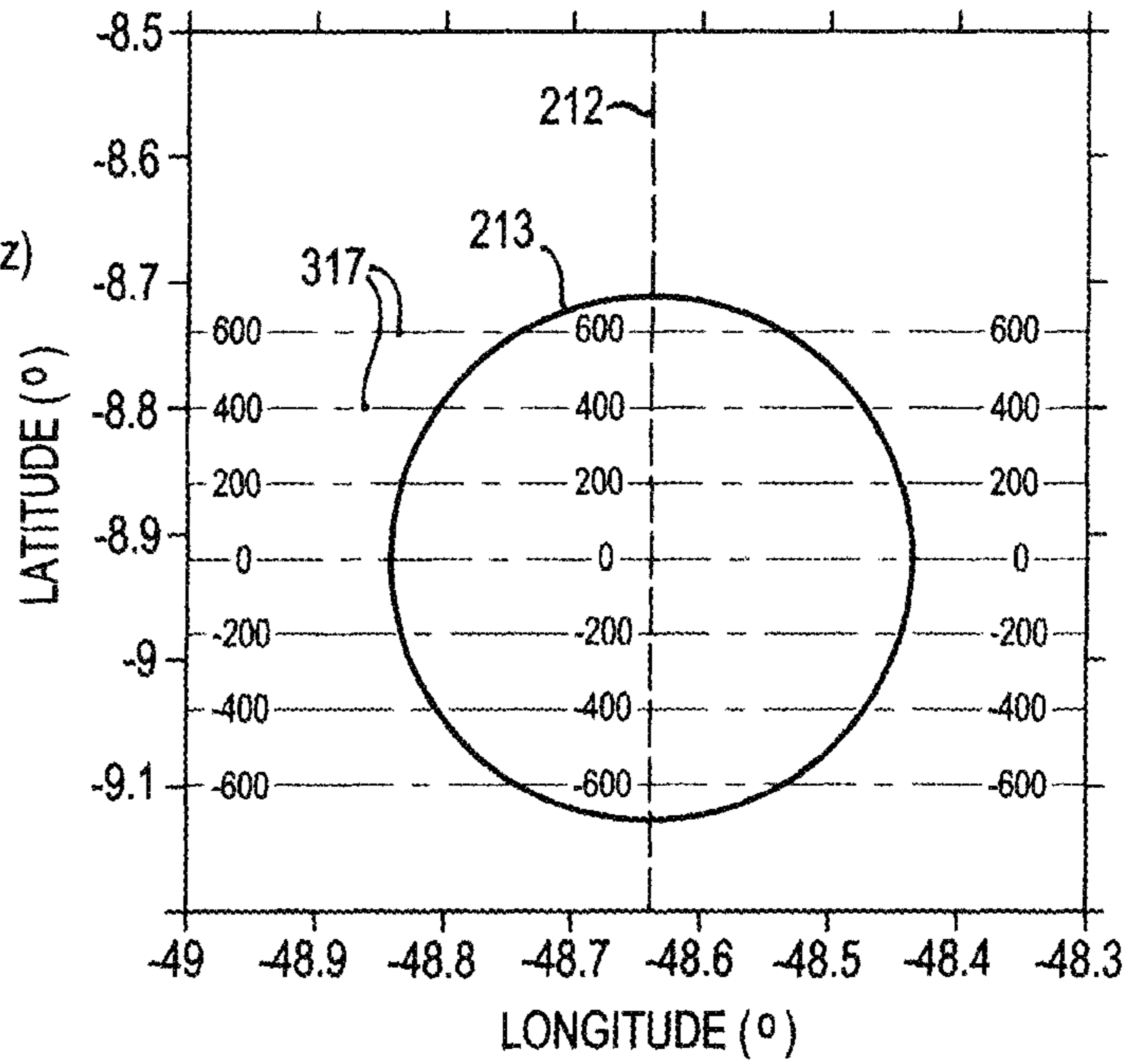


FIG. 1B



----- SATELLITE PATH
----- DIFFERENTIAL DOPPLER (Hz)
———— BEAM FOOTPRINT

FIG. 2B



----- DIFFERENTIAL DOPPLER (Hz)
———— BEAM FOOTPRINT

FIG. 2C

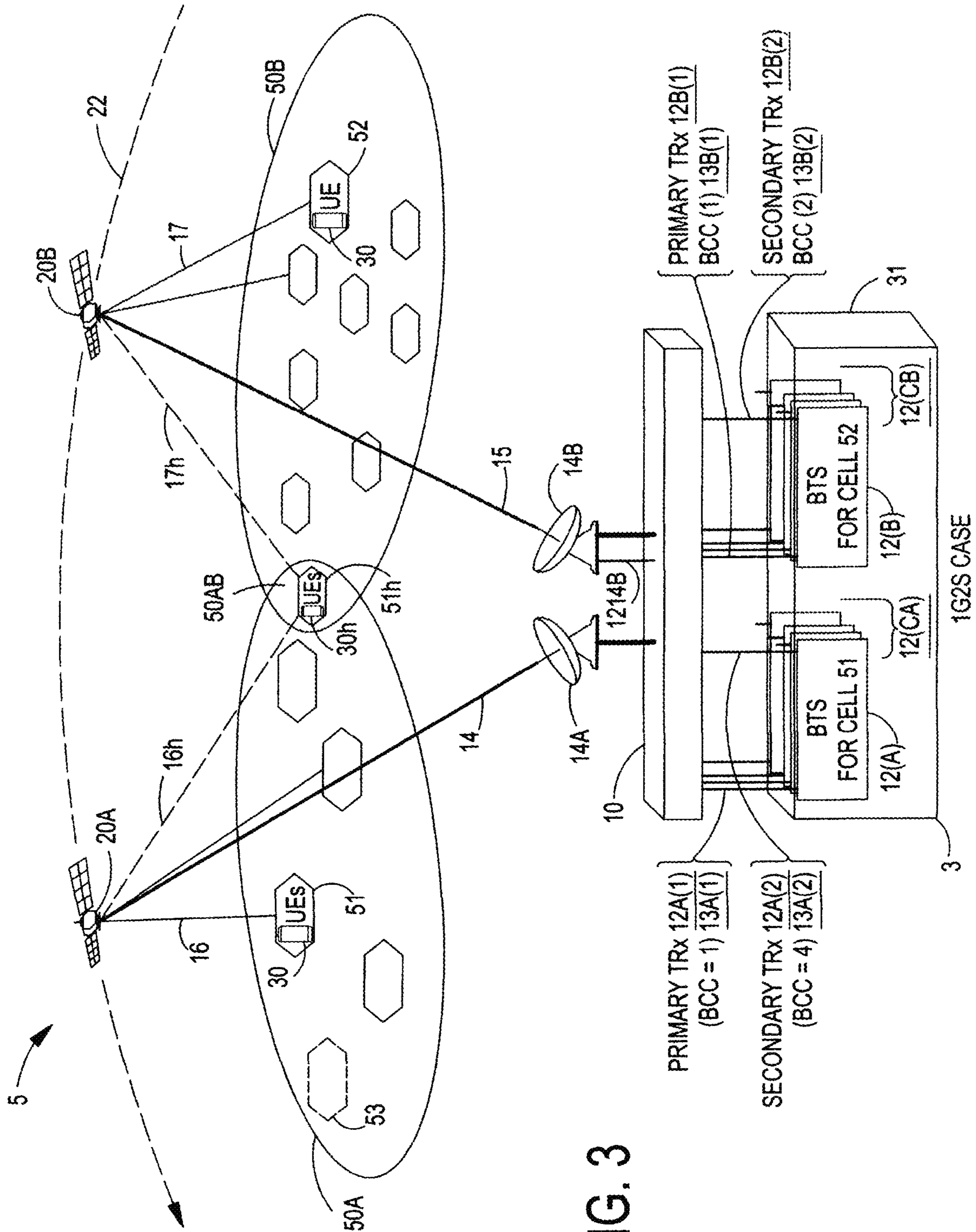


FIG. 3

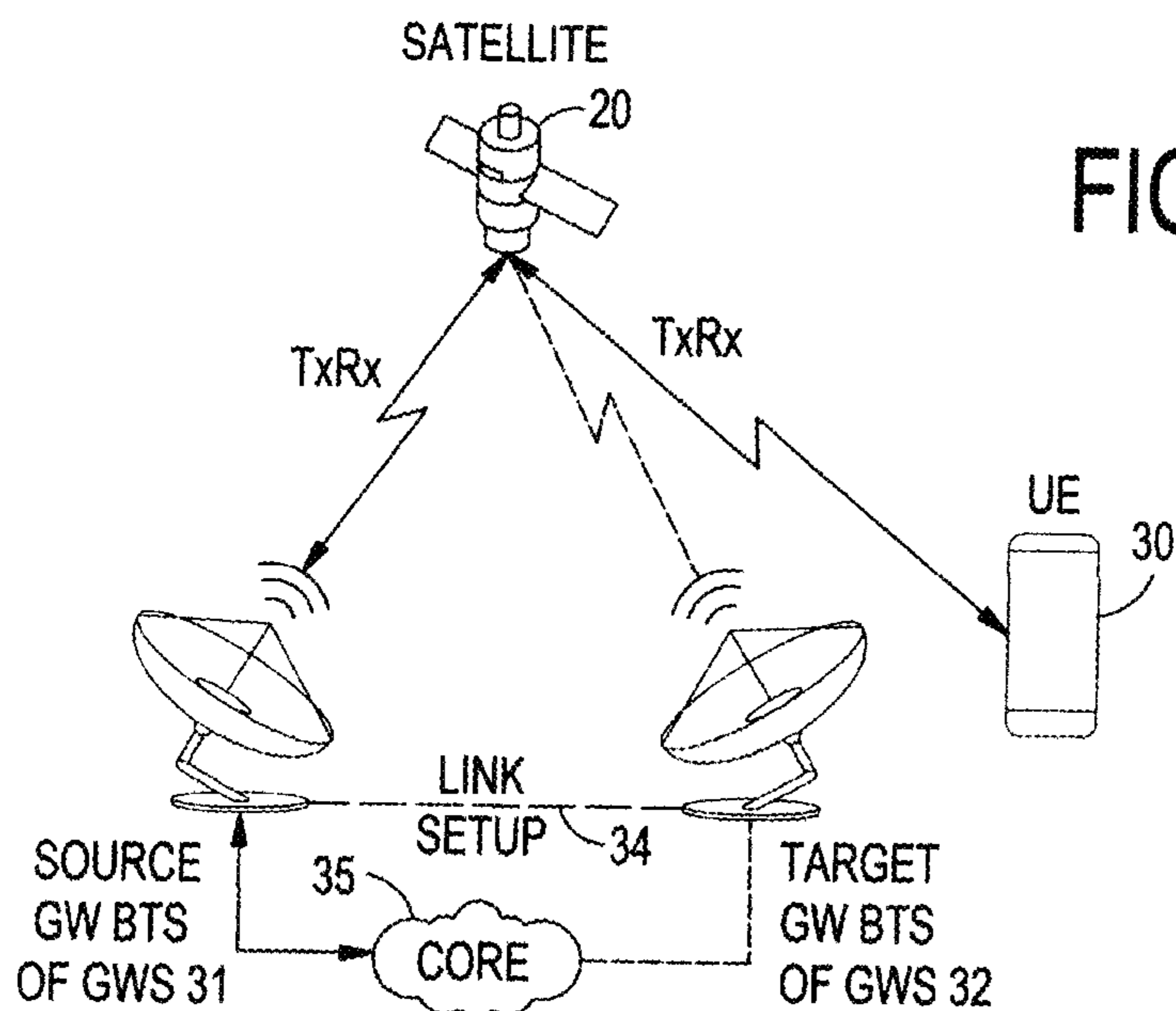


FIG. 4(a)

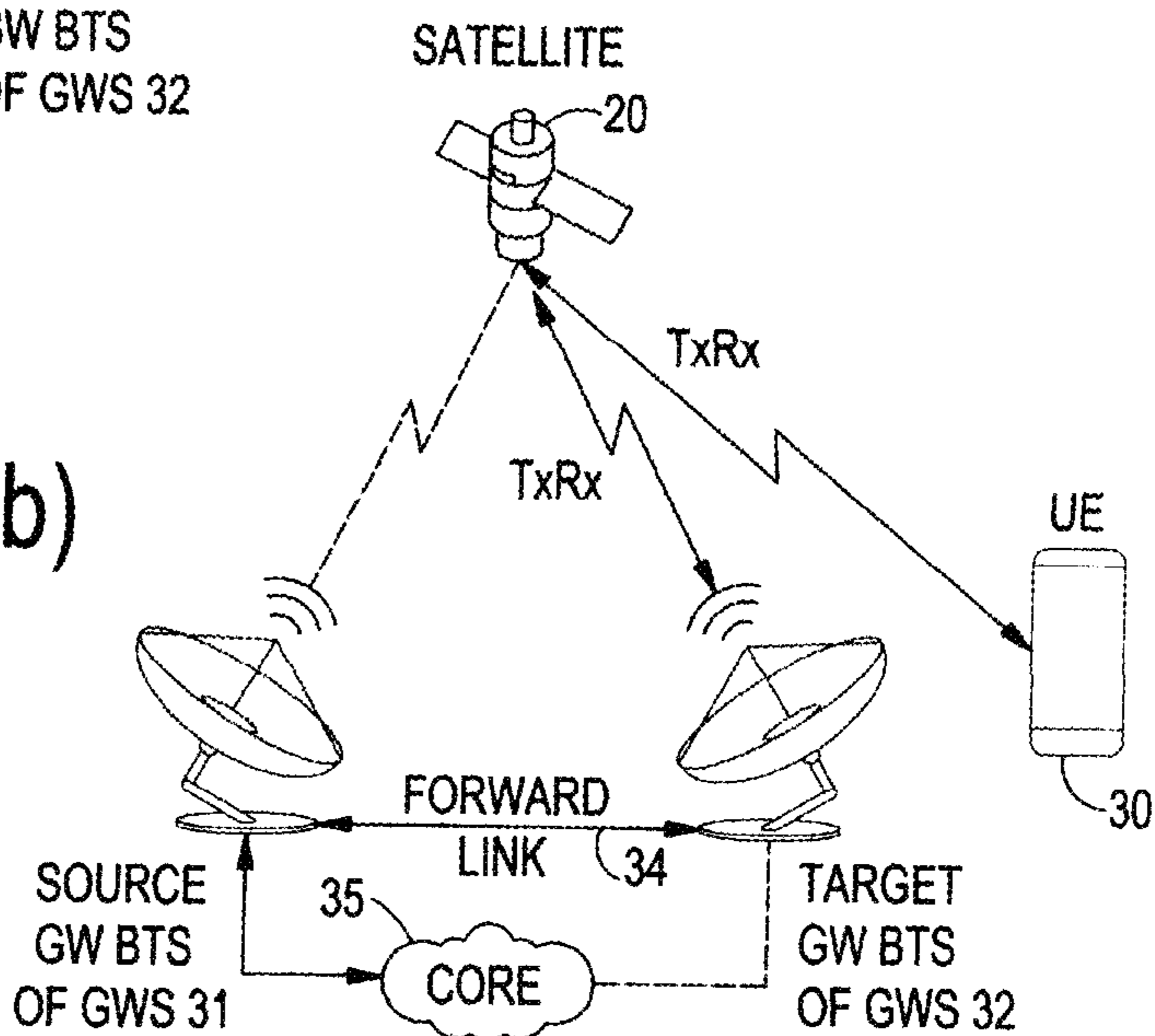


FIG. 4(b)

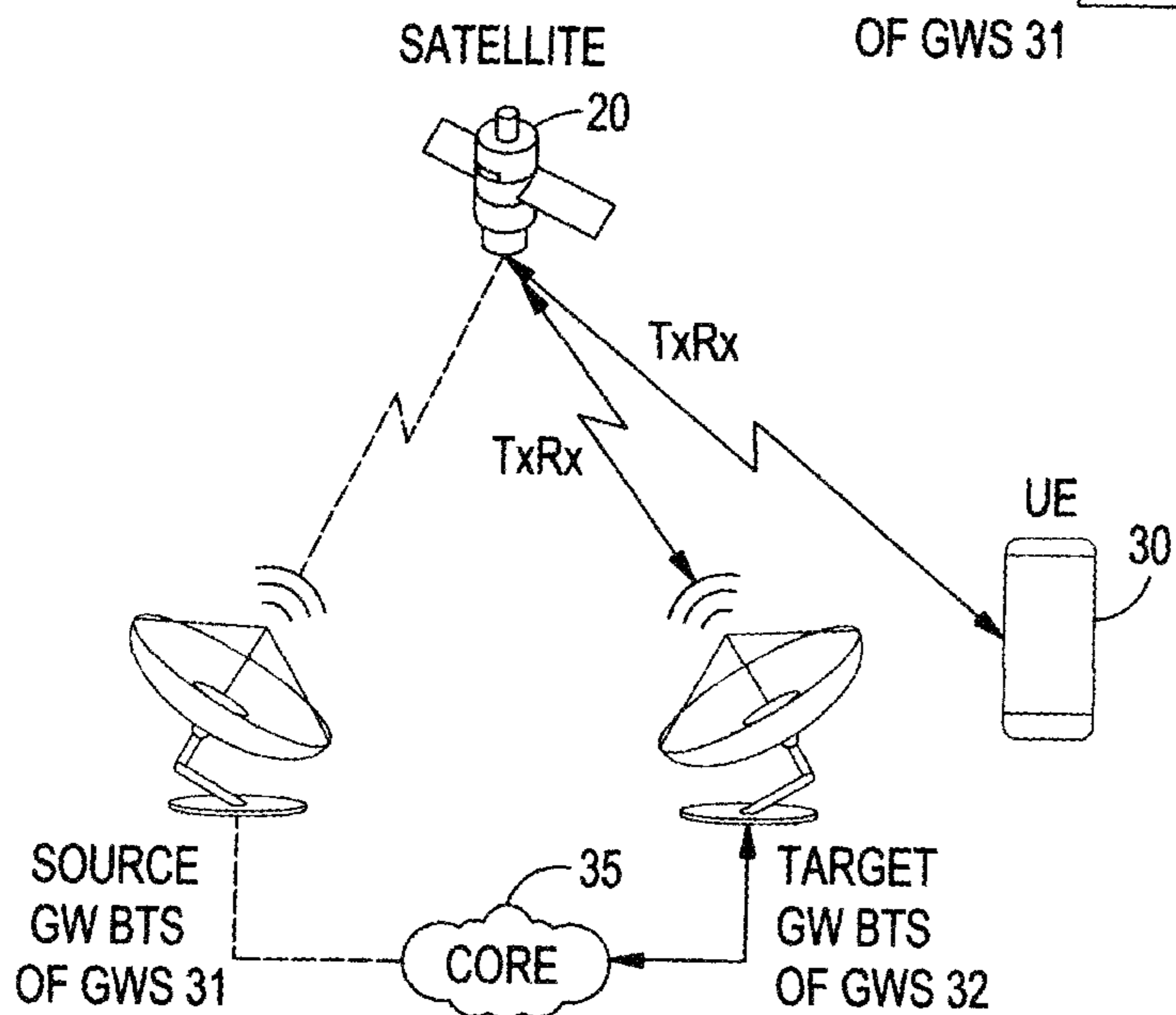


FIG. 4(c)

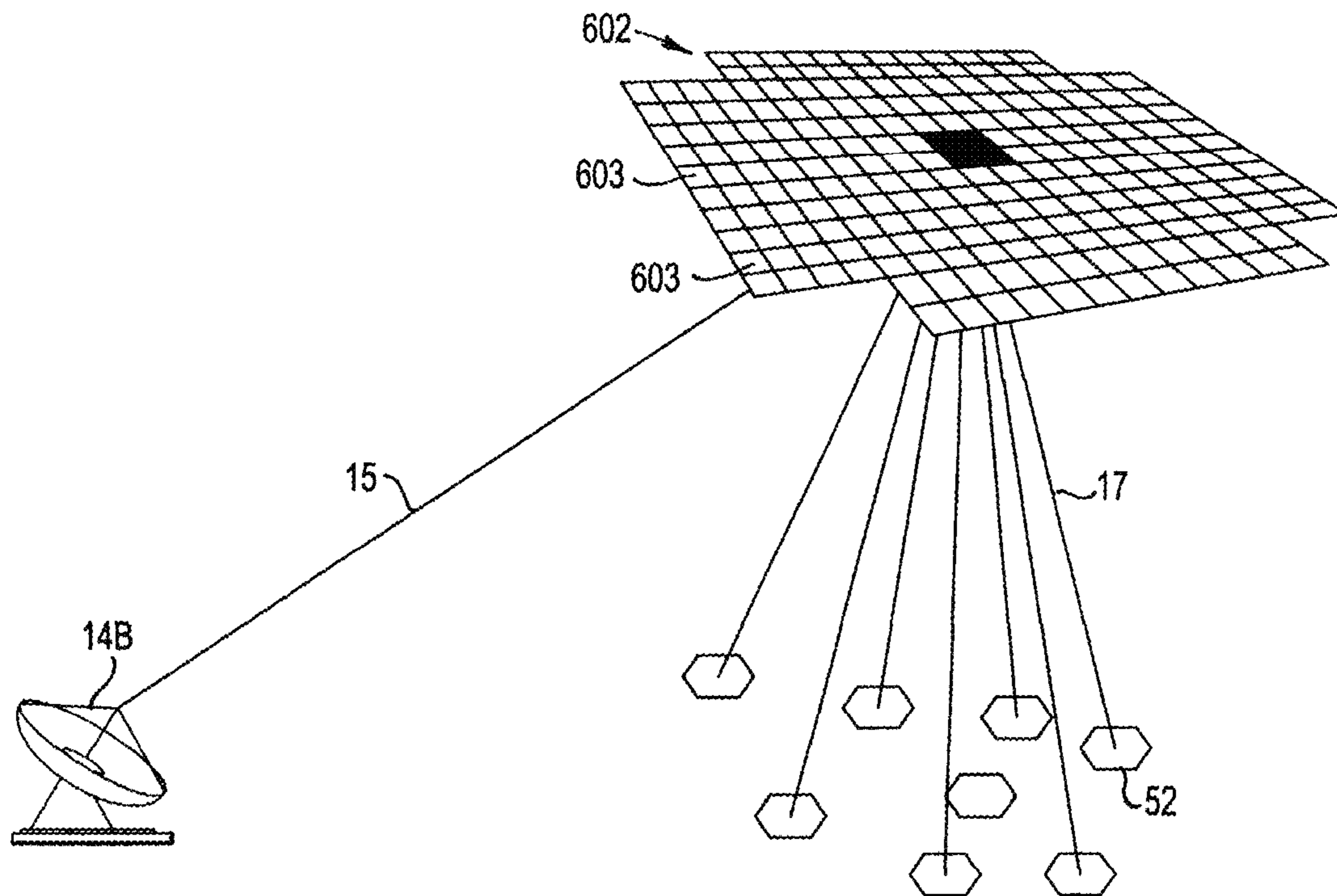


FIG. 5

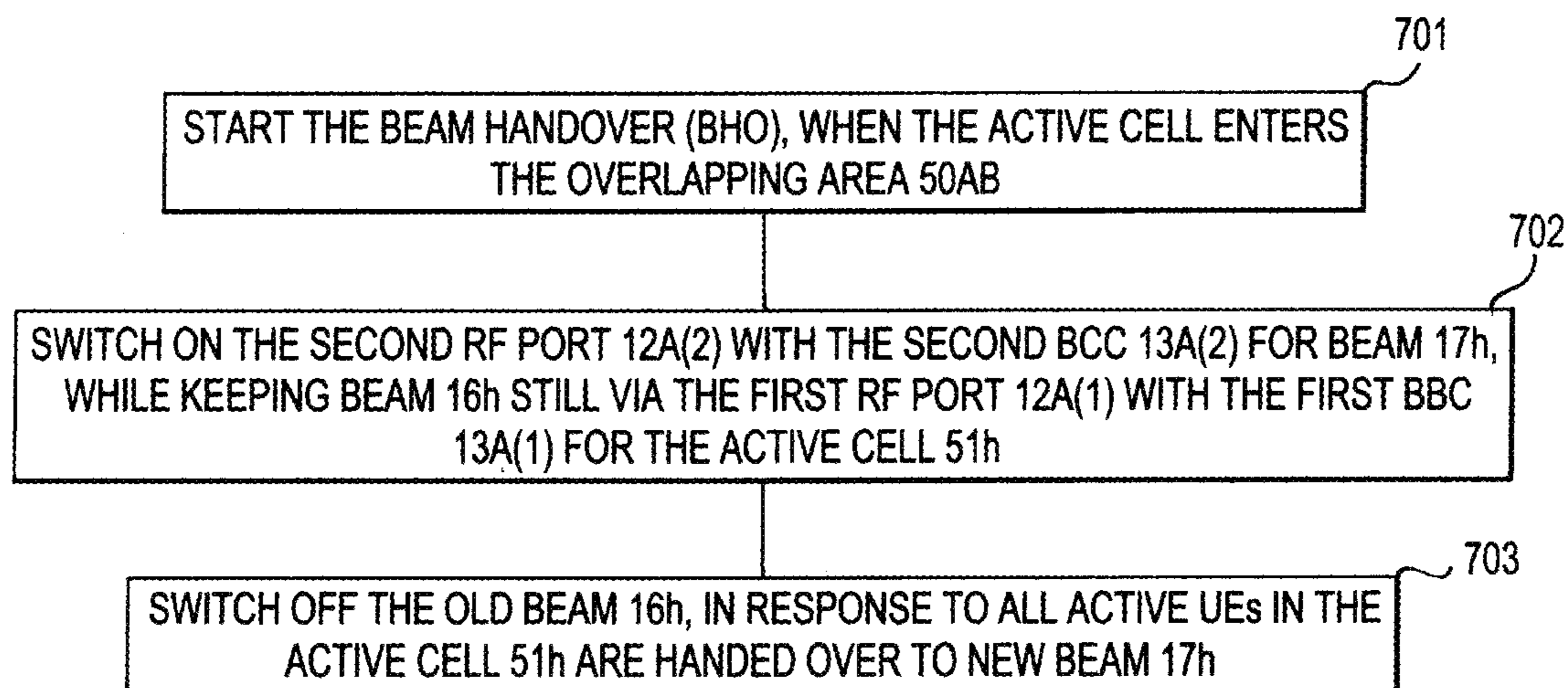


FIG. 6

SATCOM GSM SOLUTION DIRECTLY COMMUNICATE WITH GSM PHONES

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation application of U.S. application Ser. No. 17/666,234, filed Feb. 7, 2022, now U.S. patent Ser. No. 11/463,159, which claims the benefit of U.S. Provisional Application No. 63/146,322, filed Feb. 5, 2021, and the benefit of U.S. Provisional Application No. 63/165,404, filed Mar. 24, 2021. The entire contents of the applications are hereby incorporated by reference.

BACKGROUND

Being the first global telecom success, GSM has the biggest footprint on earth, its commercial success not only because it has the longest history in operation, but also the cheapest handset that meets the voice call demands as well as its well-known SMS. Its major update GPRS, and EGPRS, also started mobile internet, which paved the way for 3G 4G and 5G.

The telecom market had been moved further to 5G, but GSM is still there in most part of the world. There are still over 1 billion people globally had never owned a mobile phone, and GSM service for them is still a great improvement for their life and work. GSM is still needed in many least developed countries (listed as LDCs by UN). To them get connected enables many great opportunities. It would jump start new economic growth and make many to have better and happier lives.

However, GSM terrestrial network establishment in LDC would not be so easy, as it needs to start with telecom fixed line network infrastructure. Some places have no electricity, and only started to have solar power. There is no fixed line communication system at all for most people, and electricity coverage is not 100%. Many places also have issues maintaining the safety of the cables, equipment and the assets dotted sparsely.

Standard GSM User Equipment (UE), such as a GSM handset or GSM phone, communicates with a GSM base station (BTS) having ground-based cell towers that are within close range, typically up to 35 km and for extended TA feature 120 km. It does not communicate with a satellite, because of, for example, issues of the latency caused by the distance between base station-satellite-UE and the Doppler effect caused by the satellite at the speed of 7 km/sec to 8 km/sec, where intolerable latency and the Doppler effect with dynamic change as satellite flies over the UE being served by the satellite and on the earth, including the flying aircraft.

What is needed is a satcom GSM system directly talking to the GSM handsets which may be charged by solar power without relying on power grid and ground level telecom infrastructure over the country. To make it work, the BTS SW modification together with the latency normalization and Doppler compensation will be necessary, which are disclosed in this filing.

SUMMARY

In the present disclosure application, the innovative modifications to base transceiver station (BTS), the GSM base station, housed in gateway sites, and a new sat RAN satellite beam handover mechanism allow a constellation of satellites with large enough phase array directly talk to the GSM

handsets which may be charged by solar power without relying on mains electricity and ground level telecom infrastructure over the country or region. BTS/Core network (CN) satcom GSM of the present disclosure can directly talk to commercial unmodified GSM UEs for voice and data call.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings are incorporated in and constitute a part of this specification. It is to be understood that the drawings illustrate only some examples of the disclosure and other examples or combinations of various examples that are not specifically illustrated in the figures may still fall within the scope of this disclosure. Examples will now be described with additional detail using the drawings, in which:

FIG. 1A illustrates iso-delay contours in satellite field of view (FOV) and delay issue;

FIG. 1B illustrates differential delays for central-beam in satellite FOV after delay normalization;

FIG. 1C illustrates differential delays for beam at right edge of satellite FOV after delay normalization;

FIG. 2A is a diagram showing the Doppler issue;

FIG. 2B is a diagram of the Doppler compensation result for the cell in the center of Field of View (FoV);

FIG. 2C is a diagram of the Doppler compensation result for the cell in the edge of FoV;

FIG. 3 is an illustration of LEO satcom field of view (FoV) and the overlapping situation where beam handover happens;

FIGS. 4A, 4B, 4C are block diagrams showing Gateways interconnectivity link;

FIG. 5 illustrates an example large phase array antenna; and

FIG. 6 illustrate an example beam handover process.

DETAILED DESCRIPTION

U.S. patent application Ser. No. 17/583,992 discloses satellite radio access network (Sat RAN) beam and gateway seamless handover, the content of which is hereby incorporated by reference in its entirety.

The satcom GSM is based on GSM 3GPP specs as it aims to work with standard GSM phones user equipment (UE). The details of the global-system-for-mobiles (GSM) are fully described in 3GPP specs. The GSM frame structure is observed to let all the commercial GSM handsets work with satcom GSM. Below are the key innovative modifications on GSM BTS that enable the satcom GSM. For the efficiency of the description the text will avoid stating the terrestrial network (TN) GSM system details but focusing on the changes. Here the mobile subscriber (MS) is equivalent to user equipment (UE).

The GSM frame structure is shown in GSM 05.01, Digital cellular telecommunications system (Phase 2+); Physical layer on the radio path; General description (GSM 05.01) (etsi.org), GSM Technical Specification, Global System for Mobile Communications, Version 5.0.0, May 1996 (herein, the "GSM Specification"), the entire content of which is hereby incorporated by reference. FIG. 1 of the GSM Specification describes the frame structure of both downlink (DL) and uplink (UL) which is the same at this level with 3 timeslot offset. The sat GSM modification is done on BTS software for the UL Rx timing without any modification on GSM handsets and the BTS DL, as the DL structure to meet the expectation of an unmodified GSM UE. The BTS Rx

timing needs changes as the UL is no longer 3 timeslots, the round-trip time (RTT) can be tens of milliseconds when satellite relay is involved.

Observing the GSM specs as shown in FIG. 1 of the GSM Specification, the present disclosure shows and teaches a 5 BTS 12 (such as 12A, 12B) and a channel-routing-and-compensating device 10, which, when working with a satcom satellite network system, can turn a GSM phone into a sat phone (i.e., satellite phone) without any changes to the phone. That is, with the BTS 12 and the channel-routing-and-compensating device 10 of the present disclosure, a normal GSM phone, UE 30, can communicate directly with a satellite (such as 20A, 20B) via beam (such as 16, 17), without a ground cell tower and without any modification to normal GSM phone; and the normal GSM phone, UE 30, 15 can communicate with the BTS 12, via the satellite 20 and the channel-routing-and-compensating device 10. The mechanism that takes full advantage of the satellite is described below.

In an example embodiment, a large phase array can be used to deliver hundreds of electronically steerable beams to provide 3GPP radio access network (RAN) services to the cells fixed on the ground, for instance as shown in U.S. Pat. Nos. 11,159,228 and 10,979,133, which are hereby incorporated by reference. Delay normalization can be applied. Doppler compensation can be applied. A satellite beam handover with the BTS farm in the satellite GW sites can be enabled.

It should be noted that a normal phone on airborne plane can also be tracked and served by the satellite; and to sat RAN system, it is a moving cell configuration and can be served just as easy as a ground cell, as long as it is arranged. Or, are ground cells fixed on a surface of earth that includes land and ocean.

A diagrammatic representation of time frame structures is illustrated in FIG. 1 of the GSM Specification. As shown, 1 hyperframe has 2048 superframes, which has 2715648 TDMA frames. The hyperframe is the longest recurrent time period of the structure, and has a duration of 3 hours, 28 minutes, 53 seconds, and 760 ms (or 12,533.76 seconds). The TDMA frames are numbered modulo this hyperframe (TDMA frame number, or FN, from 0 to 2715647), and this long period is needed to support cryptographic mechanisms defined in GSM 03.20.

One hyperframe is subdivided in or corresponds to 2048 superframes, and a superframe has a duration of 6.12 seconds, and has 1326 TDMA frames. The superframe is the least common multiple of the time frame structures. The superframe is itself subdivided in multiframe, and two types of such multiframe exist in the system. A superframe has or corresponds to fifty-one 26-frame multiframe and twenty-six 51-frame multiframe. The 26-frame multiframe has a duration of 120 ms and comprises 26 TDMA frames. The 26-frame multiframe is used to carry TCH (and SACCH/T) and FACCH. The 51-frame multiframe has a duration of ≈ 235.4 ms (3060/13 ms) and comprises 51 TDMA frames. The 51-frame multiframe is used to carry BCCH, CCCH (NCH, AGCH, PCH and RACH) and SDCCH (and SACCH/C). A TDMA frame has a duration of approximately 4.62 ms, and comprising eight time slots. One TDMA frame has 8 time slots (120/26 or 4.615 ms), and one time slot has 156.25 bit durations (15/26 or 0.577 ms), where 1 bit duration is 48/13 or 3.69 μ s.

The RTT for the feeder links and service links, up and down, can be compensated to the longest one, e.g., 40 ms, then for GSM frame length, the closet one is 9 TDMA frames, or 72 time slots that provide about RTT 41.5 ms, by,

e.g., a routing-and-compensating device 10 (FIG. 3). So all the cells served by the GW (e.g., GW antenna or including GW antenna) and sat will have RTT 41.5 ms, which provide the baseline for simple BTS change to work in satellite GSM system. Other RTT values can be used according to the RF path length and the TA range, and same or similar concept applies.

Satellite (such as 20A, 20B in FIG. 3) plays a role of layer 0 (RF, the lowest physical layer) relay, taking the DL signal from BTS (such as 12A, 12B in FIG. 3) on gateway site 31 by a feeder link (e.g., in Q band) and beaming down to ground cell by the GSM service link in the local designated licensed band. GSM phone's UL signal is then picked up and sent to gateway BTS by satellite. The random-access channel (RACH) response timer is 15 seconds (3GPP TS 44.18) which is fine for RTT 41.5 ms long RF path delay. The modifications on BTS are (or include) mainly the Transmitting and Receiving timing to fit into long RF delay situations. The major changes on BTS is (or includes) a configurable parameter on the UL receiving time delay, generally in the unit of time slots. The normal BTS would have a fixed constant of 3 time slots, and with the disclosed sat RAN design, this disclosure enables very simple changes to BTS software and make it work with legacy UEs. For example, BTS (or one or more processing devices of BTS) can be configured to adjust expected receiving timing and set a timer according to the normalized delay.

The delay normalization is made to the longest delay path in the system plus the time for the signal processing, which for LEO satellite can be 20 ms for DL and UL. So an example friendly number to the BTS software modification is 72 GSM time slots which are 9 GSM TDMA frames as shown in FIG. 1 of the GSM Specification. To GSM UEs, they see exactly the same frame structure and TRx in the same way as they do to the terrestrial network (TN), hence legacy UEs are turned into satphone (i.e., satellite phone) without any changes to the phone.

The GPRS RLC layer HARQ can tolerate 40 ms in packet data call without any modification. GPRS USF takes 1 to 4 bursts to decode, then BTS expects UE UL in the next frame, that is only 4.615 ms, as UE Tx will take 20 ms to reach BTS PCU and that needs modification on the BTS side. NAS timer is usually multiple of 15 seconds which is okay for long RTT around 40 ms.

FIGS. 1A to 1C illustrate delay issue and delay normalization. For simplifying the BTS modification, the minimum delay is normalized to the longest RF path from BTS to the cell center. FIG. 1A illustrates iso-delay contours in satellite field of view (FOV); FIG. 1B illustrates differential delays for central-beam in satellite FOV after delay normalization; and FIG. 1C illustrates differential delays for beam at right edge of satellite FOV after delay normalization.

FIG. 1A shows satellite FOV 211, satellite orbital path 212, and the beams 213, 214, 215 delivered from the satellite and having 45 km diameters, and due to the FOV having dimensions of a few thousands km (shown in latitude and longitude), the amount of RF signal delay from satellite ends up different delay time. The iso-delay contours 216 shows the lines where the same delays are. Numbers overlaid on iso-delay contours 216 curves indicate the amount of the delay in the unit of ms (i.e., millisecond). For example, magnitudes of the iso-delay contours 216 are 3 ms, 4 ms, 5 ms, which are outside the scope of 3GPP GSM specs allowed RF delay, and there is no way GSM phone can talk to a standard BTS comply with 3GPP specs in such case. Furthermore, there are other challenges. FIG. 1A presents issues sat GSM faces as follows.

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RF delay longer than 3GPP specs defined range (35 km for standard, 120 km for extended).

The RF delay longer than allowed and varies with the beam.

The total RF delay needs to count the feeder link delay.

That not only make it much more outside of 3GPP spec, but also make it change with the satellite positions, as feeder link is the link between the GWS and the LEO satellite.

To resolve the issues, two steps or processes can be performed are needed, which includes, step 1, normalizing the delay to make them a constant delay; and step 2, modifying the BTS software (SW) or program instructions to adapt to the constant delay. The BTS can include, for example, one or more processing devices configured to perform functions or processes for BTS, such as to perform functions or processes that are adapted to the constant delay according to the modified BTS software (SW) or modified program instructions. The modified BTS software (SW) or program instructions may be, for example, stored on a

A routing-and-compensating device **10** (FIG. 3) can add various artificial delays to the various RF delays of beams **213**, **214** and **215** (e.g., beam centers of beams **213**, **214** and **215**) to achieve a constant delay for beam centers. For example, 0 ms, 1 ms, and 2 ms artificial delays can be added to beam centers on the three contour lines **216** with delayers of 5 ms, 4 ms, 3 ms, respectively; and accordingly beam centers on the three contour lines **216** can have same delays of 5 ms. The normalized time delay for all the cells in FOV make the delay variation range within the 3GPP spec allowed delay range, and make it possible to address the long RTT issue by simple BTS SW changes.

FIG. 1B illustrates the effect of step 1 on the central beam. FIG. 1B shows differential delay contours **217** for central beam **213** of FOV **211**. Since the normalization of the delay time is done or performed to every cell center, the delay that is left for all the cells is the relative delay from any point in the cell to the cell center, which is less than 1 microsecond as shown in the differential delay contours **217** for the central beam **213**. FIG. 1C shows differential delay contours **218** for beam **214** at right edge of FOV **211**. Differential delays of **217**, **218** are both within the 3GPP specs with regard to the delay time range, which is the basic condition to apply 3GPP specs on both BTS and UE. The key points of doing this is to make it possible for simple BTS modification to work with normal GSM phones, via modifying the BTS SW, and turn the normal GSM phones into satellite phones without any modification to normal GSM phones. In certain examples, the BTS SW can be modified to match with or be compatible with the normalized delay.

Making various delay a constant would greatly simplify the changes, and more importantly this enables both BTS and UE satellite transparent. For example, for both BTS and UE being satellite transparent, there is no need for BTS and UE to know which satellite and gateway (e.g., gateway antenna) to connect. In some examples, the effect is that BTS and UE don't even know there are satellite and gateway antenna involved. In some example, timing advance, a standard mechanism to deal with UEs in various position of a cell, can handle the delay variations only up to 70 microseconds.

Delay can be, for example, a function of ephemeris of satellite, GW or GWS positions and earth rotation, and/or cell location; and artificial delays may be introduced or added for delay normalization by a processing device in a routing-and-compensating device **10** (FIG. 3), such as

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FPGA or ASIC signal processing device that can receive instruction signals from the satellite network (NW) control system (or be under the satellite NW control system supervision) and perform delay normalization in response to the instruction signals, so that normalized delays appear constant to a BTS (such as **12A**, **12B** in FIG. 3).

The routing-and-compensating device **10** can include, for example, a routing device configured to perform routing, so as to provide right channel signals for two antennas **14A** and **14B** and BTS (such as **12A** and **12B**), and/or one or more compensating devices to normalize delay for each beam center and compensate Doppler effect for each beam center dynamically, and provide the normalized delays and compensated frequencies to the respective BTS. The one or more compensating devices may include, for example, one or more processing devices.

Each UE (or MS) has different delay, such variations at off-center locations that are off-center with respect to cell centers are small (e.g., of the order of roaming in a smaller—23 km—terrestrial cell—well within 3GPP spec defined working range.)

FIG. 2A shows another sat RAN challenge—Doppler effect well above 3GPP specified limit. FIG. 2A illustrates the Doppler issue as a result of LEO sat orbiting at the speed of 7.5 km/s. The iso-Doppler contour lines **316** are the lines where Doppler effect causes the same frequency offsets—shown as a number on the lines—which are too larger for UE to handle, as they are well beyond specs allowed range, and there are additional Doppler shift on the feeder link. The frequency offset of iso-Doppler contours **316** is the Doppler effect on the service link only and the iso-Doppler of iso-Doppler contours **316** is more than 12000 Hz, while 3GPP assumed Doppler shift is of a few hundred Hz. The sat RAN Doppler compensation mechanism is to compensate the beam with the frequency offset (e.g., to the cell center) so as to bring the Doppler effect into the 3GPP allowed range.

FIG. 2B illustrates a diagram of the Doppler compensation result for the cell in a central beam **213** that is at a center of FoV **211**, which shows an example solution that enables UE to work. Differential Doppler of differential Doppler contours **317** have values less than 700 Hz. Differential Doppler (e.g., of differential Doppler contours **317**) is the residual Doppler frequency offset after the Doppler compensation on the beam center (or cell center), where 0 Hz is indicated. With the Doppler compensation, the beam center (or cell center) has 0 Doppler offset. Away from each beam center, residual Doppler offset (or differential Doppler that is the difference with respect to the beam center) becomes larger as UE moves to the beam edge or cell edge in most cases, but none are above 3GPP assumed Doppler range after the Doppler compensation. So again, the approach brings the sat RAN use case back to the 3GPP specs where sat GSM can directly talk to normal GSM UEs.

FIG. 2C is a diagram of the Doppler compensation result for the cell **214** at the edge of FoV **211**, where the residual Doppler effect is well within the GSM UE capability defined in GSM specs. Differential Doppler of differential Doppler contours **318** have values less than 400 Hz, and accordingly GSM UEs in the cell **214** can handle that by 3GPP specs.

The Doppler compensation may be performed by one or more processing devices of the routing-and-compensating device **10**, such as FPGA or ASIC signal processing device. In some examples, Doppler pre-compensation is performed on DL, and post-compensation is performed on UL, by the one or more processing devices of routing-and-compensating device **10**, according to satellite ephemeris and latitude-

longitude-altitude (i.e., lat-lon-alt) of gateway antenna of the GWS 31 and the cell location. The pre-compensation is the process adding the opposite frequency offset before Doppler effect occurs, and post-compensation is the process adding the opposite frequency offset after Doppler effect occurs.

Doppler effect is related to the speed, direction angle changes and/or relative positions. So over the satellite path (or a period that pass over a UE), Doppler effect can be different naturally. The Doppler compensation (such as pre-compensation, post-compensation) can compensate Doppler variation during satellite pass, dynamically.

In some examples, the abrupt Doppler shift during handover can be compensated by one or more processing devices of the routing-and-compensating device 10 to be within the GSM spec, as the compensation details can be pre-arranged or pre-configured, before the satellite pass.

The pre-compensation is on a beam-to-beam basis and is based on beam-center coordinates (lat-lon). Small residual Doppler left based on UE position are within GSM spec.

To enable satellite mobility, the present disclosure provides a method of performing BHO in the satcom system. FIG. 3 illustrates LEO satcom FoV and the overlapping situation where beam handover (BHO) happens. FIG. 3 shows a gateway site (GWS) 31 in accordance with one embodiment of the present disclosure. The gateway site (GWS) 31 includes routing-and-compensating device 10, directional gateway antennas 14A and 14B, and a plurality of BTSs (e.g., eNodeBs or processing devices) 12A and 12B. The GWS 31 is in communication with user equipment (UE) 30 via a setting satellite 20A and a rising satellite 20B. The satellites 20A, 20B communicate with the UEs (such as 30) over a respective setting TRx beams 16 and rising TRx beams 17. UEs can be in an idle state and those idle UEs may only monitor the cells and carry out cell reselection and tracking area update when needed (e.g., for paging), there is no need for the BTSs to take care of them in beam or satellite handover (BHO). The BHO takes care of the active UEs only. The active UEs are or include the UEs in a call, and need BTS dedicated control to move from setting satellite beam to the rising satellite beam. The routing-and-compensating device 10, via antennas 14A and 14B, communicates with the satellites 20A, 20B over a respective outband beam 14, 15.

The satellites 20A, 20B have RAN (radio access network) signal FoV 50A, 50B on the Earth surface, respectively. The setting satellite 20A has a setting FoV 50A, and can communicate with UEs directly (e.g., without a ground cell tower and without any modification to the normal GSM UEs or phones) in their cells 51 in FoV 50A with serving beams on DL and UL. The rising satellite 20B has a rising FoV 50B, and can communicate with UEs directly (e.g., without a ground cell tower and without any modification to the normal GSM UEs or phones) in their cells 52 in FoV 50B with serving beams on DL and UL. The setting and rising FOVs 50A and 50B overlap (or at least partially overlap) in the overlapping area 50AB. The setting satellite 20A is setting, i.e., leaving the current footprint 50A for the ground station antenna 14A, and the rising satellite 20B is rising or ascending, serving the footprint 50B for the ground station antenna 14B. In accordance with one embodiment, BHO occurs for the cells 51h located inside the overlapping FOV area 50AB.

Satellites 20A, 20B are linked to the routing-and-compensating device 10, via gateway antennas 14A, 14B. The processing devices of BTS 12A, 12B control communication with the UEs via the satellites 20A, 20B on the GSM control channel (see FIG. 1 of the GSM Specification). The

satellite communication system 5 includes a ground station or GWS 31, and GWS 31 contains a farm (such as an eNodeB or BTS farm) 3 and routing-and-compensating device 10 that communicate over two satellites 20A, 20B via the antennas 14A and 14B. There may be multiple UEs 30 in a beam HO cells 51h in the satellite overlapping area 50AB (here, overlapping ground cells are labelled as 51h and non-overlapping cells are labelled 51 52. Soon cells 51 is to be changed to 52 as the satellites orbit around the earth along path or orbit 22). When UEs 30 are in a beam HO cell 51h, UEs 30 can be more specifically referred to as "UEs 30h".

The first satellite 20A is setting, i.e., leaving the current footprint 50A for the ground station antenna 14A, and the second satellite 20B is rising or ascending, serving the footprint 50B for the ground station antenna 14B.

The cells 51h in the overlapping area 50AB go through a satellite beam handover (BHO) for active UEs in HO cells 51h, e.g., in one or more HO cells 51h. That is, as the cells 51 enter the overlapping area 50AB, a satellite beam handover process is triggered to switch communication for those overlapping cells 51h from the setting satellite beams 16h to the rising satellite beams 17h. It is noted that beams 16h and 17h are slightly different from other beams of 16 and 17, as beams 16h and 17h are from the same BTS 12A in BHO, which used to be associated with the setting satellite 20A, but in beam HO (BHO), the BTS 12A is associated with both setting and rising satellites 20A and 20B. The beam 16h keeps the same as beam 16, keeping the base-station-colour-code (BCC) 13A(1); however its top priority is not on data traffic, but the active UEs HO to beam 17h which is newly started by the same BTS 12A on another RF port 12A(2) with a different BCC 13A(2) via rising satellite 20B. Beam 17h is newly added to the rising satellite beams and 16h and 17h coexist for the BHO period. Hence the BHO only happens in satellites' overlapping cells 51h of the setting satellite 20A and the rising satellite 20B. The HO beam 17h keeps the same configuration for user traffic and becomes one of the beams 17.

FIG. 3 shows a cell's BTS 12A with two RF ports 12A(1) and 12A(2), which delivers the DL and UL signals through two GW antennas 14A and 14B that serve two satellites 20A and 20B, where each baseband unit (BBU) of a cell provides a beam signal for HO service link 16h/17h via feeder link 14/15 for two TRx paths to the two RF ports 12A(1) and 12A(2) on the BTS 12A. The newly added beam 17h starts with the target GW antenna 14B with a thin line interface 1214B. Further, after the BHO and when beam 17h becomes one of the beam 17, the BHO cell is packed with the current cells in 50B, and becomes corresponding to the BTS 12B, and feed to gateway antenna 14B interface in the IQ stream, and such signal is handed over from 12A to 12B on BTS and from 14A to 14B on the GW antenna, and from feeder link 14 to 15 to achieve BHO from sat 20A to 20B. Then the data for the BHO cell is no long needed from satellite 20A and will come from 20B. This can be treated as 2 cell HO as well. Note that no extra hardware is needed, as by default there are two RF ports for each cell and BHO can just borrow one of them for short period of time, assuming the initial sat RAN of providing coverage on global scale uses 1T1R to save feeder link bandwidth. In MIMO operation, one port can be temporarily used for BHO. In some examples, the satellite GSM system can enable the RF condition of UE to achieve synchronized handover by the two beams from two satellites overlapping on to the same handover cells.

In operation, the cells **51**, **52** in the FOV of each satellite **20A**, **20B** communicate with a respective BTS **12A**, **12B** over a designated RF port. Specifically, the cells **51** in the FoV **50A** for the setting satellite **20A** communicate over a first beam **16** via the setting satellite **20A**. The setting satellite **20A** communicates with one or more first BTS (e.g., eNodeBs) **12A** of cluster **12CA** at the gateway site **31** over a primary RF Transmit/Receive (TRx) port **12A(1)**, via the first GW antenna **14A**. And the cells **52** in the FOV **50B** for the rising satellite **20B** communicate over a second beam **17** via the rising satellite **20B**. And the rising satellite **20B** communicates with one or more second BTS (e.g., eNodeBs) **12B** of cluster **12(CB)** over a primary RF TRx port **12B(1)**, via the second antenna **14B**. Each BTS may communicate with a single cell **51**, **52**.

A smooth and seamless BHO is triggered as cells enter the overlapping region **50AB**. In the beam HO moment, the two RF ports (such as **12A(1)** and **12B(1)**) are utilized separately, but for simplicity we just illustrate SIMO (Single Input Multiple Output) configuration for both satellites. Cells **51**, **52** in non-overlapping areas are using just one of the two RF TRx ports **12A(1)**, **12B(1)**, and each footprint has their own beams **16**, **17** for normal user data traffic operation. BTS **12B** has primary RF TRx port **12B(1)** with first BCC **13B(1)** and secondary RF TRx port **12B(2)** with second BCC **13B(2)**.

FIG. **6** illustrate an example beam handover process. Referring to both FIGS. **3** and **6**, when the active cell **51** enters the overlapping area **50AB**, the satcom system tells (or instructs) the BTS (e.g., eNodeB) to start the BHO (**701** of FIG. **6**). For example, the BTS may start the BHO, in response to receiving a start BHO instruction signal sent from the satcom system when the active cell enters the overlapping area **50AB**. When the cells **51** are in the overlapping area **50AB**, the BHO is ON and the cells **51** become BHO cells **51h**, beams **16** become beams **16h**, and UEs **30** become UE **30h**. BHO happens in the overlapping area **50AB**. The process of moving all the active UEs from setting satellite beam **16** to the rising satellite beam **17** is started.

The BTS **12A** switch on the second RF port **12A(2)** with the second BCC **13A(2)** for beam **17h**, while keeping beam **16h** still via the first RF port **12A(1)** with the first BCC **13A(1)** (**702** of FIG. **6**). The source beam **16h** and target beam **17h** are overlaid on the same physical cell **51h**, fixed on the ground, with two different BCCs **13A(1)** and **13A(2)**, respectively. Therefore, UEs **30h** in cell **51h** can recognize beams **16h** and **17h** as corresponding to two different cells, and satellites BHO can be realized by using the BCCs, alternatively. The BTS's two RF ports **12A(1)**, **12A(2)** deliver the ping-pong BCCs to the cell **51h** via two RF paths **16h**, **17h** and two satellites **20A**, **20B**.

In response to that all active UEs in the active cell **51h** are handed over to new beam **17h**, the BTS **12A** (e.g., eNodeB or baseband unit (BBU) of BTS) behind the two overlapping beams **16h** and **17h** switches off (or controls to switch off) the old beam **16h** (**703** of FIG. **6**), as there is no need to keep or have the old beam **16h** for the active UEs in the active cell **51h**. Once BTS **12A** communicates over the secondary port **12A(2)** via the second antenna **14B** and the rising satellite **20B** to the active UEs **30h** in cell **51h**, BTS **12A** ceases communication over the primary port **12A(1)** and the first antenna **14A** to the active UEs **30h** in cell **51h**, and the cell **51h** can continue to communicate with the BTS **12A** over the secondary RF port **12A(2)** and the second antenna **14B**, where the respective BTS (e.g., eNodeB or BBU) **12A** of cluster **12CA** may become or be taken as BTS (e.g., eNodeB or BBU) **12B** of cluster **12CB**, and the respective secondary

RF port **12A(2)** and BCC **13A(2)** of the BTS **12A** of cluster **12CA** may become or be taken as the primary RF port **12B(1)** and BCC **13B(1)** of the BTS **12B** of cluster **12CB**.

The coexisting beams **16h** and **17h** from two RF ports **12A(1)** and **12A(2)** via two GW antennas **14A**, **14B** and two satellites **20A** and **20B** can improve the reliability of the BHO. BTS **12A** switches off beam **16h** only when beam **17h** has taken over, and further BHO may not change BTS (e.g., eNodeB or BBU of BTS) for the cell, so all the active UEs context are kept and seamlessly take effect as needed, as it is the same BTS before and after BHO. After the BHO, beam **17h** becomes **17**, UEs **30h** are back to generic UEs **30** until the next BHO.

For more details of BHO, references can be made to U.S. patent application Ser. No. 17/583,992, noting that physical cell ID (PCI) used in LTE scenarios is replaced with BCC for GSM scenarios. For example, PCI **13A(1)** can be replaced with BCC **13A(1)**, PCI **13A(2)** can be replaced with BCC **13A(2)**, PCI **13B(1)** can be replaced with BCC **13B(1)**, and PCI **13B(2)** can be replaced with BCC **13B(2)**.

FIGS. **4A**, **4B**, **4C** illustrate gateways interconnectivity link. Certain gateways may be hundreds to over 1000 km apart and addressing the UE mobility between cells that have their serving BTSs on different gateway sites (such as different gateway sites **31**, **32**).

FIGS. **4A**, **4B**, **4C** illustrate an example gateway handover (GHO) for UE mobility from cell **51** to cell **53** (as shown in FIG. **3**). The GHO may have three phases: preparation (FIG. **4A**), execution (FIG. **4B**), and completion (FIG. **4C**).

During the preparation phase (FIG. **4A**), the UE **30** is connected to the source GW BTS in GWS **31** and from there to the core network **35**. In some examples, the core network **35** is formed by multiple nodes, which offer multiple functionality such as mobility management, authentication, session management, setting up bearers and application of different Quality of Services. At some point, when UE **30** moves to cell **53** whose target GW BTS is in a different GWS **32**, the target GW BTS receives a handover notification of beam HO, the target GW BTS can receive the timing of the new corner and knowing exactly the UE and the active service, so that the core network reroute its traffic to the right BTS. During the execution phase (FIG. **4B**), the UE **30** is connected to the target GW BTS in GWS **32** but the traffic is routed via the gateway interconnection link (forward link) **34** to the source GW BTS in of GWS **31** and then the core network **35**. Finally, at the completion phase (FIG. **4C**), the UE **30** is connected to the target GW BTS of GWS **32** and from there to the core network **35**. Thus, communication between the satellite **20** and the core network **35** is originally through the source GW BTS in source GWS **31**, and transferred to the target GW BTS in GWS **32**.

FIG. **5** shows an example build-in large phase array satellite **602**. The phase array satellite **602** includes a plurality of phase array antenna elements **603** that form a plurality of (e.g., hundreds of) beams **17** which are electronically steerable to provide continuous services to the fixed cells on the ground. The feeder link **15** from GWS tracking dish **14B** is providing the DL and UL mechanism between the satellite and the GWS, and the satellite is capable of talking to a number of GWSs at the same time. Satellites **20A**, **20B** can each be (or include), for example, the large phase array satellite **602**.

The first challenge of satcom technology talking to GSM UEs (or MSs) is to provide cells just like terrestrial network (TN) deployment as the GSM UE knows it, as the mobility, paging and location area are all cell based. Although satcom avoids the need of infrastructure and equipment like towers,

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antennas on the ground, the BTS is still needed in the BTS farm on gateway site to provide beams from satellite for cells **51** and **52** under FOV of satellites **20A**, **20B**, as shown in FIG. **3**, for un-modified UE (or un-modified MS) to perform or operate.

Example first innovative solutions of the satcom GSM to the first challenge are described as follow.

In some examples, ground gateway sites (GWSs), such as GWS **31** shown in FIG. **3** and other GWSs, are distributed around the earth, and can control enough number of satellites whose FOVs **50A**, **50B** cover the earth surface.

In certain examples, each satellite **20A** or **20B** has large enough number of phase array antenna elements (such as antenna elements **603**), which have enough elements to form a few hundreds beams for Tx and Rx to serve many cells in satellite FoV on the Earth surface; as satellites pass the cells **51**, **52**, each cell gets a serving beam, and satellites are tracking the cells during their passes or paths (**22**) over each ground cell.

In another example, there are enough satellites orbiting in LEO and distributed in multiple orbital planes to cover the whole earth surface in dynamic fashion. Setting satellites (such as **20A**) can handover the services to rising satellites (such as **20B**) smoothly without interruption.

GWS (such as **31**) can then send the many DL signals to the satellites with specific packing order to let satellites arrange the beams and deliver them to the pre-arrange fixed cells, where many beams are formed for delivery of each DL for the cells.

With the same phase arrays (or the same phase array antenna elements), the Rx beams for each cell can be formed and each cell's UL signals are received in the similar way for BTS (such as **12A**, **12B**).

To enable satcom to work with un-modified GSM phones, modifications are required on the BTS side specially to handle the additional latency caused by the long RF path of feeder link and service link of 700 km LEO orbit, compared to its normal operation working with a tower at no more than 10 Km.

The second challenge is the latency caused by the distance between GWS-satellites-UE, where the latency may be about 5 to 16 ms, and changing dynamically as satellite flies over the cells as indicated by FIG. **1A**. Such a factor can be difficult for BTS and UE to handle, as BTS and UE would not assume satellites would be involved at any stage at any time. The problems are that (1) BTS and UE do not know where the satellites are at any moment, and (2) such variations would disturb the frame structure of GSM as shown in FIG. **1** of the GSM Specification.

Example second innovative solutions to the second challenge can include getting the longest RF path latency and count the delay of various factors, including but not limited to the following.

Information about each satellite and earth cell, such as their position (Latitude, Longitude, height) are well captured and fully under GWS control.

BTSs (Such as **12A**, **12B**) generate the DL signals in IQ form and pass them to routing-and-compensating device **10** and antennas **14A** and **14B** to pass them to serving satellites (such as **20A**, **20B**), and serving satellites pass them to UEs in respective cells (such as **51**, **52**). UL signals come back from UEs in cells (such as **51**, **52**) to serving satellites (such as **20A**, **20B**), and to antennas **14A** and **14B** and the routing-and-compensating device **10**, and further to BTSs (Such as **12A**, **12B**).

In some examples, according to the beam's position, different amount of artificial delay is introduced, and the

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delay is normalized by a delay and doppler compensator of routing-and-compensating device **10**, using complex unit with the required phase to produce the product on each IQ, so as to have constant delay and expected frequency observed by BTS (such as **12A**, **12B**). For example, depending on the position of the satellite (such as **21A**, **20B**) and position (e.g., elevation from the ground) of GW antenna (such as **14A**, **14B**) of GWS **31** and UE, the latency or delay can vary. Artificial delay can be added, such that the compensated or normalized delay has the same value (or approximately same value) as seen by the BTS (such as **12A**, **12B**), regardless of satellite position. Then the constant delay can be handled by BTS software (SW) modifications, so that the delay issue is simplified and BTS does not need to consider where the satellite is on LEO. All the BTSs can work in the same or similar way regardless where satellites are. The residual delay differences are small and within spec defined range as shown in FIGS. **1B** and **1C**.

The residual timing differences can be handled with the normal timing advance (TA) control of BTS (such as **12A**, **12B**), because the residual timing differences are within the tolerance of the BTS. Accordingly, the implementation is simplified and the signal processing is streamlined.

In some examples, for a cell size of 48 km, since the normal 3GPP TA range are for (or correspond to) up to 35 km, an elevation angle of a $\cos(35/48)=43.183^\circ$ can make the beam differential TA in 35 km for 48 km cell size, where the elevation angle is an angle between ground and the beam from the satellite to the cell. For an elevation angle larger than 43.183° , the beam differential TA is still within the normal 3GPP TA range. For an elevation angle smaller than 43.183° , an extended TA range needs to be used. The normal 3GPP relevant RAT TA range and/or the extended TA (for GSM) range can be used by BTS (such as **12A**, **12B**).

The amount of delay may be configured by delay compensator of the routing-and-compensating device **10**, e.g., by FPGA processing device and memory holding the IQ signals for the required amount of time, so that UE at each cell center has a mid TA value, which is a midpoint value of a range of TA value, such as a 3GPP TA range.

For Sync mechanism of the system, DL/UL follow the GPS Clock and is sync to UTC as LTE does (as performed or controlled by BTS).

In some example, changes are made to BTS to accommodate the gateway-satellite-UE long RF path delay (as normal DL and UL would be kept as 3 time slots as usual). One of the required change is in the timers. The BTS's timer is set, such that the BTS may set a longer gap from the Tx to the expected Rx signal from UE UL, e.g. $41.5 \text{ ms} + 3$ timeslot period. In some examples, a one-way gap may be 20 ms.

With the fixed latency (a few GSM frames), the extra long RACH delay can be further handled, where BTS (such as **12A**, **12B**) may waste (or skip) first a few RACHs and respond to the later ones. GSM timer on BTS side for receiving the RACH can be set long enough so that there is no problem. The good thing about GSM RACH for satcom GSM is that they start with the strongest power level so that satellites would not miss them. In some examples, the power level may be 30 dBm. Accordingly, the satellites (such as **20A**, **20B**) are able to hear the RACH and respond within the period of timer setting (e.g., 15 seconds).

The third challenge is the Doppler effect due to the satellite speed of 7 km/sec to 8 km/sec as shown in FIG. **2A**.

The GWSs (such as **31**) can be configured to compensate the Doppler effect for the DL and UL signals for each cell location as shown in FIGS. **2B** and **2C**. The delay and

doppler compensator device of the routing-and-compensating device **10** can be used for this purpose. The residual Doppler effect can be, for example, within ± 600 Hz. The residual Doppler effect is well within GSM spec, so that both normal GSM UE and BTS can work smoothly.

On the return journey for UE UL signals, GWS can do the same (or similarly) for BTS DL signal in Doppler effect compensation and delay normalization.

The fourth challenge is the handling of USF. In TN deployment, BTS would expect the UL Tx on the very next frame, but for the long RF path in satcom case, it will take much longer time. Thus, on packet data for GPRS/EGPRS, we can modify the BTS software to expect the UL signal with the extra normalized delay time. Such change can properly adjust the RTT latency issue here. In certain example, the BTS software can be modified to expect the UL signal with the extra normalized delay time, so as to match with or be compatible with the extra normalized delay time.

The fifth challenge is the beam tracking of ground cells, beam handover from satellite to satellite and gateway handover. This is due to low earth orbit (LEO) satellites are rotating around the earth and earth self-rotation. The solution is a combination of below build-in capabilities in the satcom GSM system.

The satellites (such as **20A**, **20B**) can include massive phase array (or phase array antenna elements) with beam-forming capability dynamically steering the beams as the relative position between the ground cells and their serving satellites changes, so the cells being served are tracked as long as the cells are in the FOV of satellites.

Satellites' FoV (e.g., **50A**, **50B**) overlap among themselves in overlap areas (such as **50AB**) to cover the area being served, leaving no gap on the ground where services are needed.

When a cell is shifting out of FoV **50A** of the setting satellite **20A**, it is also entering FOV **50B** of the rising satellite **20B**. Beam handover between two satellites **20A**, **20B** is performed during the cell is in the overlapping area **50AB** of the two satellites **20A**, **20B**.

Each BTS has two BCCs, **13A(1)** and **13A(2)**, as shown in FIG. 3, assigned to the two BTS RF ports, **12A(1)** and **12A(2)**, respectively, and each BTS RF port is streaming the IQ baseband signal with the routing-and-compensating device **10** serving the two satellites **20A** and **20B**, and the two satellites **20A** and **20B** have overlap FOV area **50AB** that the beam handover cell **51h** is in. The two beams **16h** and **17h** are overlaid on the same cell and the BTS would initiate the beam HO and tell UE to find rising satellite beam to the cell with another BCC, which is the one the BTS generated for the rising satellite.

After taking the measurement report from the UE in the overlapping area of the setting and rising satellites **20A** and **20B**, the BTS can use the rising satellite **20B** to continue the service to the UE. Beam HO is accomplished seamlessly.

Referring to FIG. 4, the gateway handover is performed with the proper gateway placement, so that one satellite is able to see two GWs (such as GWs of GWSs **31** and **32** shown in FIG. 4) while its FoV has cells served by the two gateways (e.g., two GW antennas). There are enough transponders on satellite that can talk to the relevant GWs while satellite needs to serve their cells. GW handover is accomplished as the satellites pass the cells.

Core NW support to the GW/BTS are assumed (or provided) for CS and PS services, just like TN deployment. The GW HO (i.e. GHO) can go through three phases as shown

in FIG. 4 and associated text. The timing and procedures are similar to TN, and able to cover longer distance via forward links **34** (such as fiber links).

The 6th challenge is the UE mobility support, where cell handover between two cells whose BTS are in two gateway sites far away from each other (e.g. 1000 km away). Although this is a standard feature of GSM specs, the enabling mechanism in satcom need specific inter gateway links as shown in FIG. 4. The HO involved 3 phases of setup from control channel to the traffic and clearing down the extra link after the HO. These phases involve the satcom radio innovative approaches as described above (such as approaches to address the first to fifth challenges) to enable 3GPP HO protocols running in between the sites and entities as protocols do in TN deployment. Some timers need to be tuned to accommodate RTT 40 ms. For example, in 2G, most of timers are set to 5 to 15 seconds, therefore there is good tolerance to long delay introduced by GWs and satellites.

In the present disclosure, with the resolutions and improvements in BTS/Core network, satcom GSM can directly talk to commercial GSM UEs for voice and data call.

In certain examples, in the satellite communication system of present disclosure, gateway placement is such that the satellites serving cells of the gateways have the line of sight (LOS) to the gateways for smooth GW HO.

Thus, the present disclosure provides a GSM satellite communication system **5** in communication with a first satellite **20A** having a first field of view **50A** including a first plurality of cells **51** in which a first plurality of UE **30** are located. The UE **30** are in direct communication with the first satellite **20A**. The system **5** includes a first feeder link **14** and a first tracking antenna **14A** configured to communicate with the plurality of active UEs **30** via the first satellite **20A** directly serving the first plurality of cells **51**. The system **5** also has a first BTS **12A** (e.g., a first processing device) configured to communicate with the plurality of active UEs **30**; a routing-and-compensating device (e.g., a second processing device) configured to normalize delay for a plurality of beam centers of the first plurality of cells **51**, and provide the normalized delay to the first BTS **12A**. The routing-and-compensating device **10** can enable the BTS **12A** to tolerate communications with UE **30** via the first satellite **20A**, by normalizing delays and compensating Doppler effect and providing normalized delays and compensated frequencies to BTS **12**. In the present disclosure, residual timing differences within a cell **51** can be handled with the normal timing advance (TA) control of BTS **12A**, because the residual timing differences after the delay normalization are within the tolerance of the BTS **12A**. The advantage of the sat RAN design is to make the sat RAN two technology transparent to each other, i.e. the BTS (or eNB and gNB) and UE do not need to manage which satellite and gateway they need to talk to, while satellite technology does not need to manage the RAN details, but the provision of the RF condition as a communication condition. The physical enabling mechanism for the direct link between the satellites and UEs is or includes the large enough phase array on the satellite. BTS and UE just perform their modem operation as normal, provided BTS (or eNB and gNB) has the modifications needed to handle long RTT for tens of milliseconds.

In describing the illustrative, non-limiting embodiments illustrated in the drawings, specific terminology will be resorted to for the sake of clarity. However, the disclosure is not intended to be limited to the specific terms so selected, and it is to be understood that each specific term includes all technical equivalents that operate in similar manner to

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accomplish a similar purpose. Several embodiments are described for illustrative purposes, it being understood that the description and claims are not limited to the illustrated embodiments and other embodiments not specifically shown in the drawings may also be within the scope of this disclosure.

What is claimed is:

1. A global-system-for-mobiles (GSM) satellite communication system in communication with a first satellite having a first field of view including a first plurality of cells in which a plurality of active User Equipment (UEs) are located,

the plurality of active UEs being in direct communication with the first satellite, the satellite communication system comprising:

a first feeder link and a first tracking antenna configured to communicate with the plurality of active UEs via the first satellite directly serving the first plurality of cells; a first processing device configured to communicate with the plurality of active UEs; and

a second processing device configured to normalize delay for a plurality of beam centers of the first plurality of cells, and

provide the normalized delay to the first processing device,

wherein the second processing device is further configured to perform Doppler compensation for the plurality of beam centers of the first plurality of cells, and provide compensated frequencies to the first processing device.

2. The GSM satellite communication system of claim 1, wherein:

timing advance of the UE at a beam center of the plurality of beam centers has a midpoint value of a range of timing advance with the normalized delay.

3. The GSM satellite communication system of claim 1, wherein:

the first processing device is a processing device of a GSM base transceiver station; and

the second processing device is configured to normalize delay for beam centers of the first plurality of cells according to a GSM frame structure.

4. The GSM satellite communication system of claim 1, wherein:

the first processing device is configured to adjust expected receiving timing and set a timer according to the normalized delay.

5. The GSM satellite communication system of claim 1, wherein the first satellite includes a plurality of phase array antenna elements configured to form a plurality of beams for the first plurality of cells.

6. The GSM satellite communication system of claim 1, wherein the first satellite is configured to track the first plurality of cells when the first satellite passes over the first plurality of cells.

7. The GSM satellite communication system of claim 1, wherein:

when an elevation angle between ground and a beam from the first satellite to a cell of the first plurality of cells is equal to or larger than a threshold value, a normal 3GPP timing advance range is used; and

when the elevation angle is smaller than the threshold value, an extended timing advance range is used.

8. The GSM satellite communication system of claim 7, wherein the threshold value is 43.183 degrees.

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9. The GSM satellite communication system of claim 1, wherein:

the first processing device is a processing device of a GSM base transceiver station; and

the first processing device is connected to a core network.

10. The GSM satellite communication system of claim 1, wherein:

the first tracking antenna is in a first gateway site;

the GSM satellite communication system further comprising:

a second gateway site; and

a fiber link between the first and second gateway sites.

11. The GSM satellite communication system of claim 1, wherein:

the first processing device is a processing device of a GSM base transceiver station; and

the first satellite is transparent to the GSM base transceiver and unmodified standard 3GPP compliant UEs and is configured to communicate with a modified base-station low PHY of the GSM base transceiver and the unmodified standard 3GPP compliant UEs.

12. The GSM satellite communication system of claim 1, wherein:

the first satellite is a first setting satellite; and

the GSM satellite communication system is in communication with a second rising satellite having a second field of view, the first setting satellite and the second rising satellite having an overlapping field of view where the first field of view overlaps with the second field of view, and an overlapping plurality of cells being located in the overlapping field of view;

the GSM satellite communication system further comprising:

a second feeder link and a second tracking antenna configured to communicate with the second rising satellite serving a plurality of active UEs directly in a second plurality of cells; and

the first processing device is further configured to control the plurality of active UEs to communicate directly with the second rising satellite.

13. The GSM satellite communication system of claim 12, wherein:

the first processing device is configured to start or end beam handover in response to an instruction signal.

14. The GSM satellite communication system of claim 12, wherein:

the plurality of active UEs in the first field of view communicate directly with the first setting satellite over a plurality of first service link beams; and

the plurality of active UEs in the second field of view communicate directly with the second rising satellite over a plurality of second service link beams.

15. The GSM satellite communication system of claim 14, wherein:

the first antenna communicates with the first setting satellite over a first feeder link; and

the second antenna communicates with the second rising satellite over a second feeder link.

16. The GSM satellite communication system of claim 15, wherein the first processing device is further configured to control the active UE to cease communicating with the first setting satellite.

17. The GSM satellite communication system of claim 15, wherein the first antenna stops communicating with the first setting satellite.

18. The GSM satellite communication system of claim **12**, wherein the first processing device is configured to:
communicate with the active UE in the overlapping field of view with a first base-station-colour-code (BCC) and via the first setting satellite; and
communicate with the active UE in the overlapping field of view with a second BCC and via the second rising satellite, when the active UE becomes in the overlapping field of view.

19. The GSM satellite communication system of claim **1**, wherein the first processing device is configured to:
adjust expected receiving timing to match with the normalized delay; and
communicates with the plurality of active UEs via the second processing device, the first tracking antenna, the first feeder link, and the first satellite.

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